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This experiment considers whether V50 depends on the mass of an armor sample when the material and thickness are constant. V50 is the velocity at which 50% of the shots are stopped by the armor. It was hypothesized that V50 values determined using lighter armor samples may be overly optimistic because lighter armor samples have more rearward motion during impact thus requiring more velocity for penetration. V50 was determined for 75mm x 75mm and 150mm x 150mm square samples of A36 sheet steel with a thickness of 6.35 mm for 3 bullets, the M80, the M193, and the M855. The armor samples were placed in contact with 10% ballistic gelatin prepared per the FBI protocol. For all three bullets, the V50 was higher for the lighter armor samples (75 mm square) compared with the heavier samples (150 mm square), indicating that lighter samples are harder to penetrate.

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Does V50 Depend on Armor Mass?

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Abstract
This experiment considers whether V50 depends on the mass of an armor sample when the material and thickness are constant. V50 is the velocity at which 50% of the shots are stopped by the armor. It was hypothesized that V50 values determined using lighter armor samples may be overly optimistic because lighter armor samples have more rearward motion during impact thus requiring more velocity for penetration. V50 was determined for 75mm x 75mm and 150mm x 150mm square samples of A36 sheet steel with a thickness of 6.35 mm for 3 bullets, the M80, the M193, and the M855. The armor samples were placed in contact with 10% ballistic gelatin prepared per the FBI protocol. For all three bullets, the V50 was higher for the lighter armor samples (75 mm square) compared with the heavier samples (150 mm square), indicating that lighter samples are harder to penetrate.

Introduction
V50, a standard metric for quantifying armor performance, is the velocity at which a projectile penetrates a given armor type 50% of the time. Final acceptance is normally based on full sized armor so it is not at risk of testing bias due to difference in armor size. Although fielded personal armor chest plate designs are usually close to 250 mm x 300 mm, armor development often uses smaller armor samples to reduce sample costs. The purpose of this experiment is to analyze the effects the sample size of armor has on V50. A recent study published by the 23rd International Symposium on Ballistics (Singletary et al., 2007), found that V50 was higher for lighter armors (constant material and thickness) using soft armor and pistol bullets. Singletary et al. (2007) found that increasing armor size from 380 mm to 457 mm side length seemed to decrease V50. Here, we hypothesize that smaller the sample size (mass) of armor the more effective the armor will be in stopping the bullet from penetrating (higher V50), because the armor will move more during bullet impact creating a longer stopping distance and longer interaction time.

Method
Steel plate armor was tested against three different types of bullets: M80, M193 and M855. The M80 bullet is 7.62 mm in diameter and of conventional construction with full metal jacket with a lead core and weighs 9.39 grams. The M193 bullet is 5.56 mm in diameter and of conventional construction with full metal jacket with a lead core and weighs 3.56 grams. The M855 bullet is 5.56 mm in diameter, armor piercing due to a steel penetrator in the front, and weighs 4.01 grams. Two armor plate sizes were used for each bullet, a 75 mm square steel armor plate and a 150 mm square steel armor plate. The steel plate is made of A36 sheet steel and is 6.35 mm thick. Each armor plate was held flush against 10% ballistic gelatin prepared per the FBI protocol (MacPherson, 1994). Remington 700 rifles in 7.62x51mm and 5.56x45 mm were fired from 4m in front of an optical chronograph with LED sky screens. The chronograph provided velocity measurements with an uncertainty of 0.3%. The armor samples were placed 1.3 m downrange from the chronograph. Velocity in feet per second was recorded along with penetration which is shown by a 0 (no penetration) or 1 (penetration). Ten shots were taken for each combination of bullet and armor size, as muzzle velocity was varied to achieve a sufficient number of shots both stopped and penetrating.

Results

For each bullet and armor mass, penetration probability was graphed vs. impact velocity. V50 was then determined by least-squares logistic regression to the model for the penetration probability as a function of velocity, $f(v) = 1 - 1/(1 + (v/V50)^b)$. The analysis method employed here differs from MIL-STD-662F, which is designed only for acceptance testing, does not provide an uncertainty estimate for V50, and only uses a subset of the available data points. In contrast, this analytical regression-based approach uses all the data points, provides an estimate of the uncertainty in V50, and is appropriate for comparing V50 under differing test conditions rather than merely determining acceptance or rejection relative to a lot acceptance threshold.

Using the M80 bullet with the 75 mm square armor sample, regression analysis shows V50= 589.60 m/s and for the 150 mm square armor sample, V50=584.91 m/s. Using the M193 bullet with the 75 mm square armor sample, regression analysis shows V50=699.21 m/s and for the 150 mm square armor sample, V50=683.03 m/s. Using the final bullet M855 with the 75 mm square armor sample, regression analysis shows V50=632.73 m/s and for the 150 mm square armor sample, V50=607.18 m/s. The penetration V50 of each bullet is higher with the smaller sample size. Figures 1-6 show the penetration vs. velocity along with the best fit model in each of the six cases.

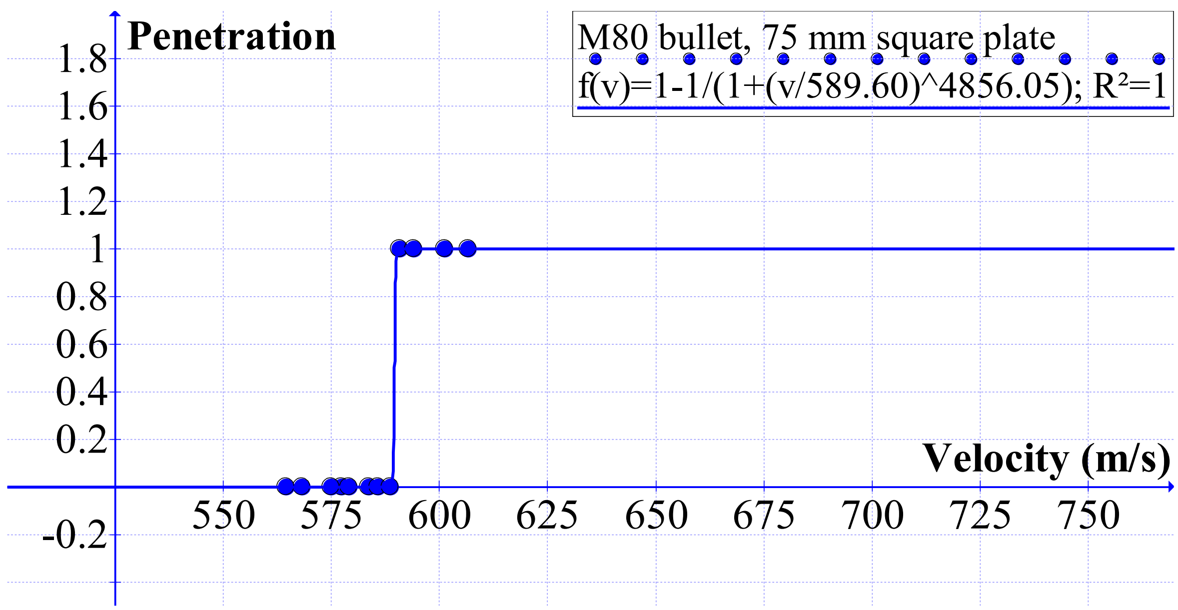

Figure 1: Penetration of the M80 bullet in this 75mm square steel plates. Regression analysis shows V50=589.60 m/s.

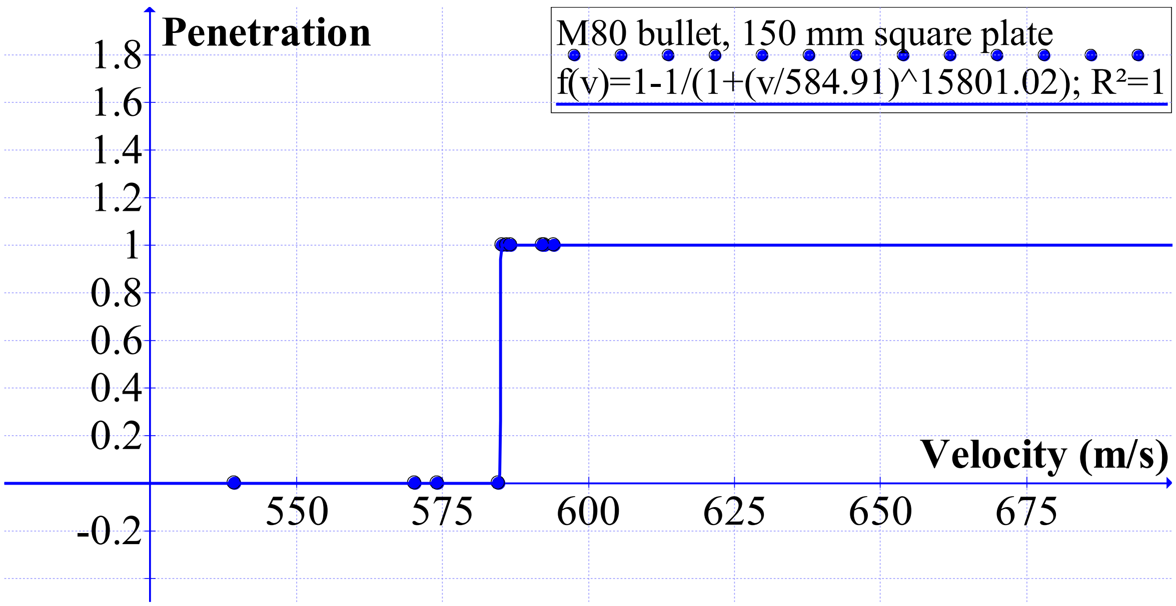

Figure 2: Penetration of M80 bullet in 150mm square plate. Regression analysis shows V50=584.91 m/s.

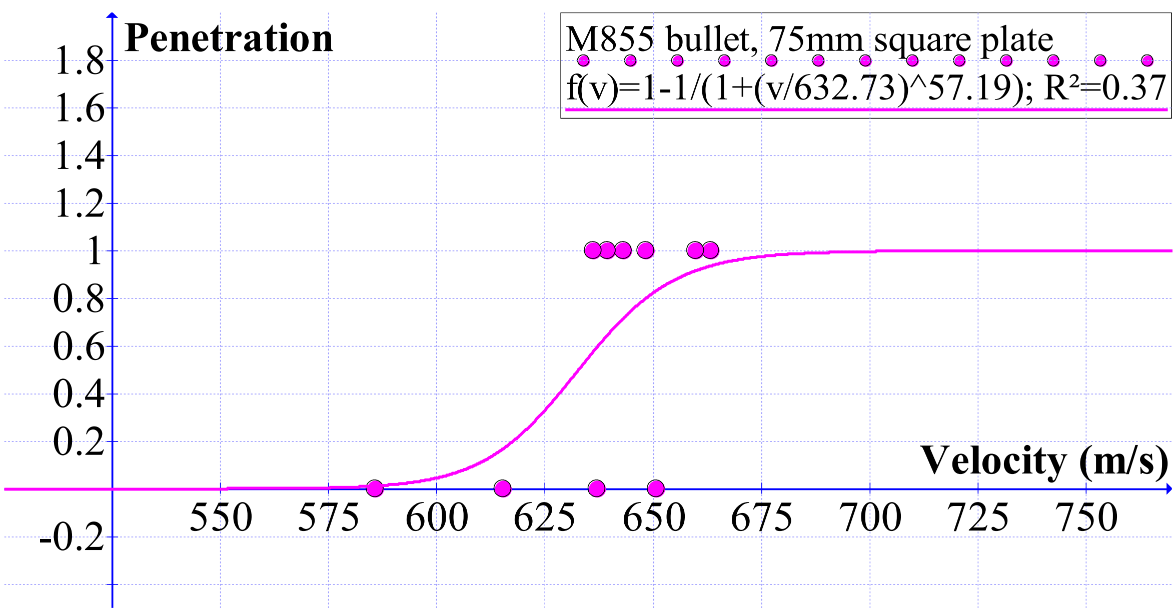

Figure 3: Penetration of M855 bullet in 75mm square plate. Regression analysis shows V50=632.73 m/s. This bullet demonstrates a much larger zone of mixed results.

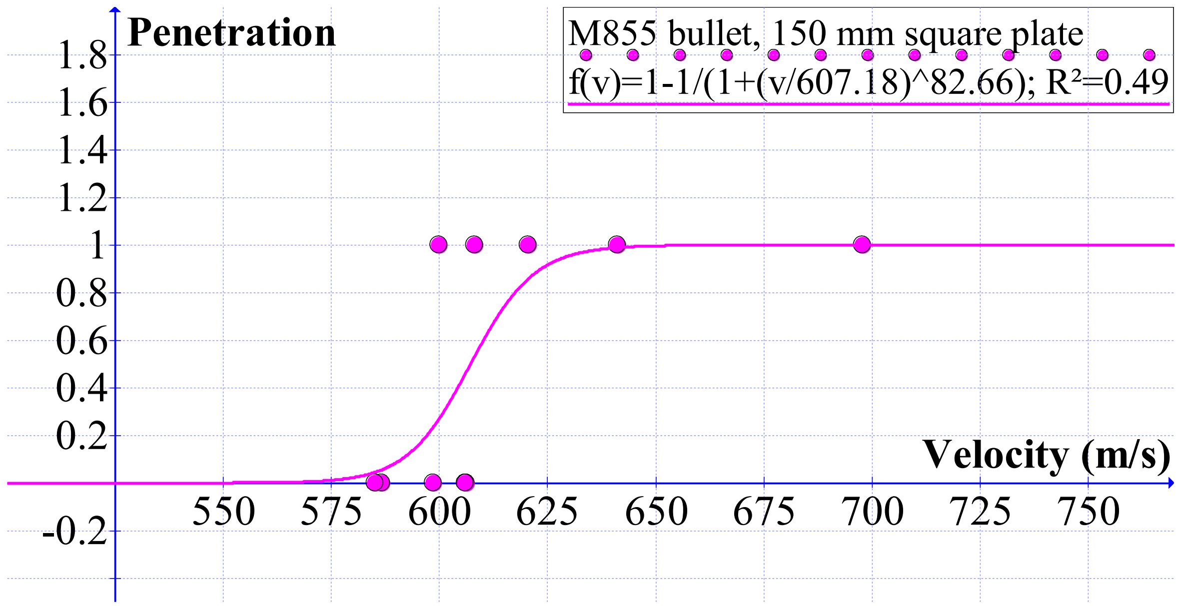

Figure 4: Penetration of M855 bullet in 150mm square steel plate. Regression analysis shows V50=607.18 m/s. This bullet shows a significant zone of mixed results.

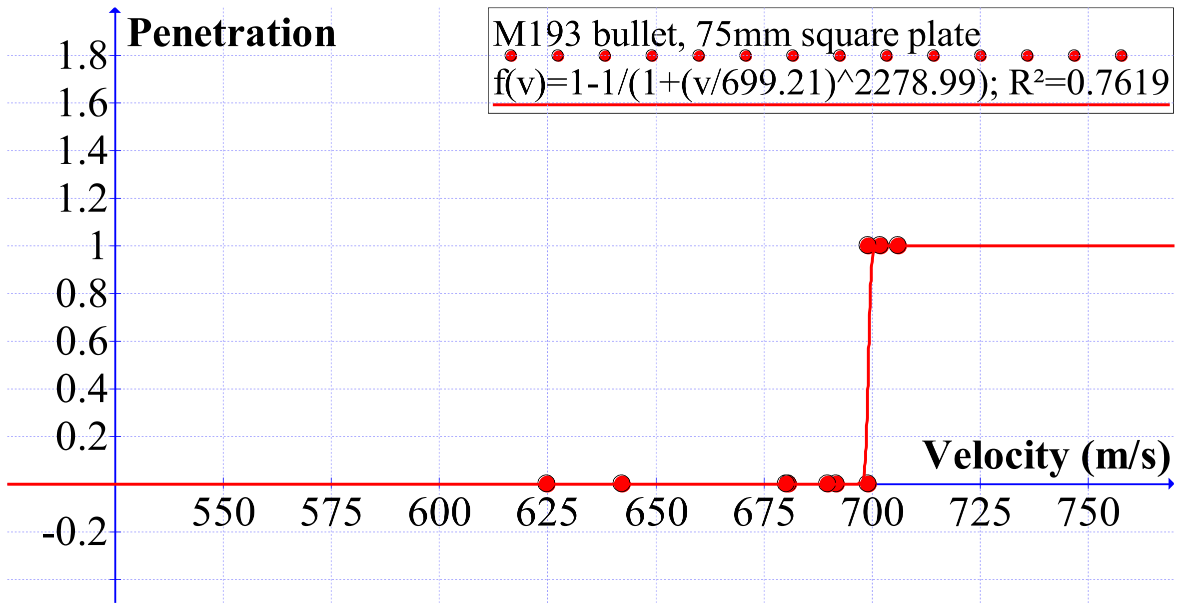

Figure 5: Penetration of M193 bullet in 75mm square steel plate. Regression analysis shows V50=699.21 m/s.

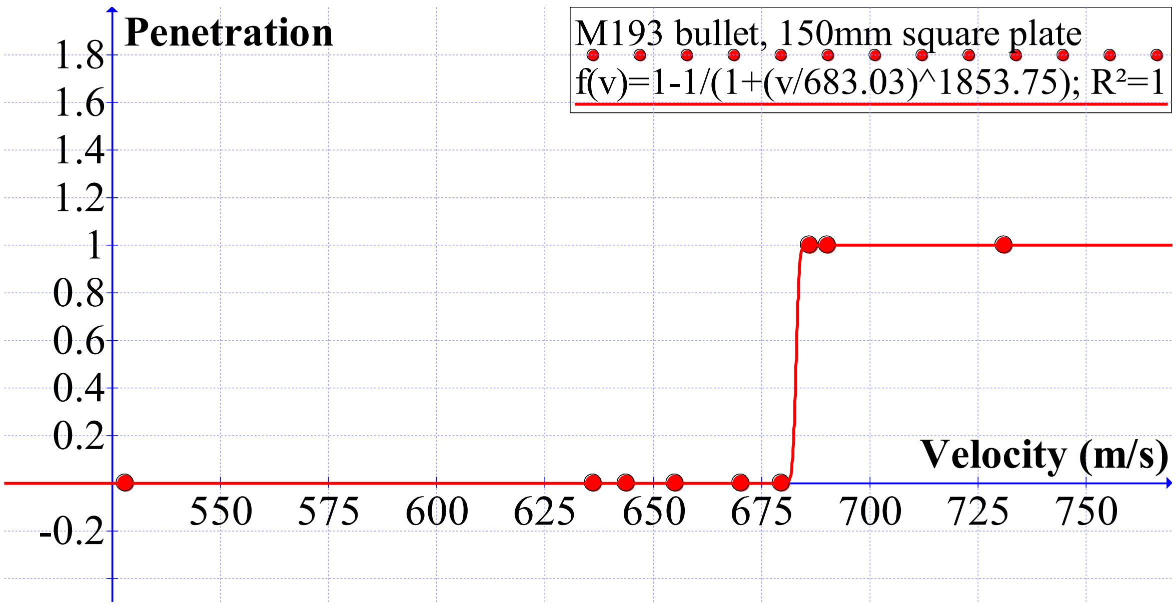

Figure 6: Penetration of the M193 bullet in 150mm square plate. Regression analysis shows V50= 683.03 m/s.

For each of the graphs above, an R squared is given from regression. The R squared is an indicator of how well the data fits the model. The closer the value is to 1, the better the data fits the curve. For the M80 bullet, both the 75 mm square and 150 mm square armor plate's R squared are 1.000 meaning the data points for this graph fit the curve well. For the M855 bullet and the M193 bullet the R squared is often lower than 1 illustrating that the data points do not always fall on the curve, due to a zone of mixed results. The zone of mixed results is a range of velocities over which a higher velocity than the lowest velocity demonstrating a penetration does not always yield penetrations. Table 1 summarizes the V50 in each case as well as the difference in V50 between the larger and smaller plate sizes.

Bullet	**V50 (m/s) for 75 mm square plate**	**V50 (m/s) for 150 mm square plate**	**Difference (m/s)**	**Uncertainty (m/s)**
M80	589.60	584.91	4.69	2
M193	699.21	683.03	16.18	3
M855	632.73	607.18	25.55	15

Table 1: V50 for bullet through a 75 mm square plate and a 150 mm square plate. In each case the lighter (smaller) armor plate has a higher V50 than the heavier (larger) armor plate of the same material and thickness.

Discussion

For each of the three rifle bullets tested, smaller, lighter armor sample sizes have a larger V50. The lighter samples are harder to penetrate because they move backwards more with the bullet impact increasing the contact time and contact distance. It is common for laboratories developing new armor designs to use 10 to 15 cm square armor tiles to reduce development costs. It is shown that under sized armor plates are harder to penetrate. It is likely that undersized armor plates yield overly optimistic V50 values compared with full sized armor

plates. The study also suggests that a full sized armor that could move rearward with less resistance during impact might have a higher V50 than the identical armor that was more constrained regarding its rearward motion. For example, an energy absorbing material used to reduce the risk of behind armor blunt trauma might have the added benefit of increasing V50 if the armor could move rearward more freely during bullet impact.

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